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Introduction

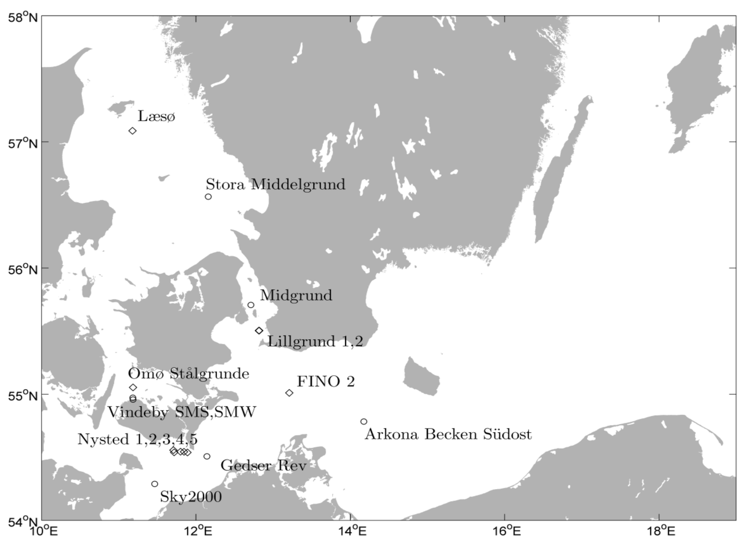
In the EU-Norsewind project (2008-2012) one task was to assess the wind climate in the Baltic Sea using Synthetic Aperture Radar (SAR) observations. The presentation outlines the methodology and key results. The Baltic Sea has been mapped relatively frequently by Envisat ASAR since 2002 and during these years several offshore meteorological masts have been in operation.

The first step was to assess the accuracy of SAR-based wind mapping in this region. We compared SAR-based wind maps retrieved from ANSWRS the APL/NOAA SAR Wind Retrieval System. The NOGAPS wind direction data were interpolated in space and time prior to input in CMOD-5. Around 900 collocated pairs of observations were found between the SAR-based wind maps and the 10 offshore meteorological masts. The statistical comparison on wind speed (direction) showed root mean square error 1.17 m/s (6.29°), bias of -0.25 m/s (7.75°), standard deviation of 1.88 m/s (20.11°), and linear correlation coefficient R^2 of 0.783 (0.95°).

The second step was estimation of the mean wind speed, the Weibull scale and shape parameters, and energy density based on over 1000 SAR-based wind maps for the Baltic Sea. The results were compared to the FINO-2 meteorological mast data.The SAR-based results from the 12 existing and 42 planned offshore wind farm sites within the study area including parts of Danish, Swedish, German, and Polish Seas were extracted and showed variability in wind energy density from 300 to 800 W m^{-2}. The wind energy density as a function of distance to nearest coast was also investigated (Hasager et al. 2011).

The third step is focused on lifting SAR-based winds from 10 m to hub-height using a method proposed and applied to a data set in the North Sea by Badger et al. 2012 (EWEA 2012 conference). In brief, the method is based on information of the atmospheric stability and the boundary layer height using WRF mesoscale results and applying this information to a model for the vertical profile in the marine boundary layer between 10 m and hub-height (Peña et al. 2008). The results of step 3 are currently in progress but no results can be presented.

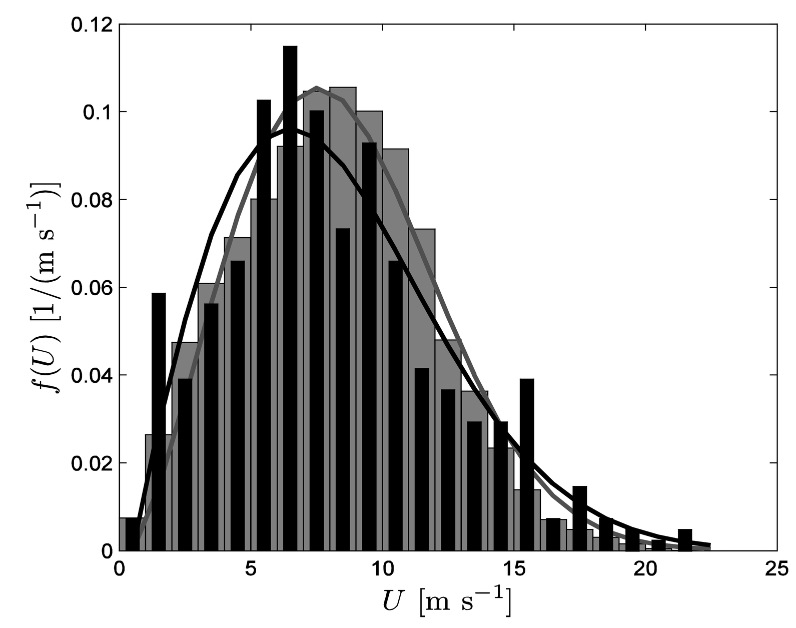
Comparison SAR winds vs. met-data winds



	FINO2	Lill.1	Lill.2		Nys.1		Nys.2		Nys.3	Nys.4	Nys.5	Omø	ALL
	Free	Free	Free	Wake	Free	Wake	Free	Wake	Free	Free	Wake	Free	**ALL**
N	165	23	77	42	87	47	63	46	155	56	35	35	**927**
R^2	0.952	0.965	0.881	0.971	0.859	0.764	0.805	0.881	0.970	0.970	0.972	0.971	**0.950**
SD	18.95	16.64	16.63	22.67	15.94	19.65	17.51	13.85	15.73	15.70	15.07	16.16	**20.11**
RMS	5.79	4.37	7.86	5.44	8.16	12.68	10.38	6.56	3.85	3.84	3.56	3.88	**6.29**
Bias	−8.44	−11.59	47.16	20.08	48.54	22.71	32.46	12.89	6.83	17.97	5.24	3.02	**7.75**
Slope	1.01	1.05	0.87	1.01	0.86	0.83	0.90	0.93	1.01	1.00	0.97	0.98	**0.99**

Location of met-masts and table with results of comparison on wind speed between SAR winds and met-masts winds for free wind sector (no wind farm) and wake sectors (including wind farm).

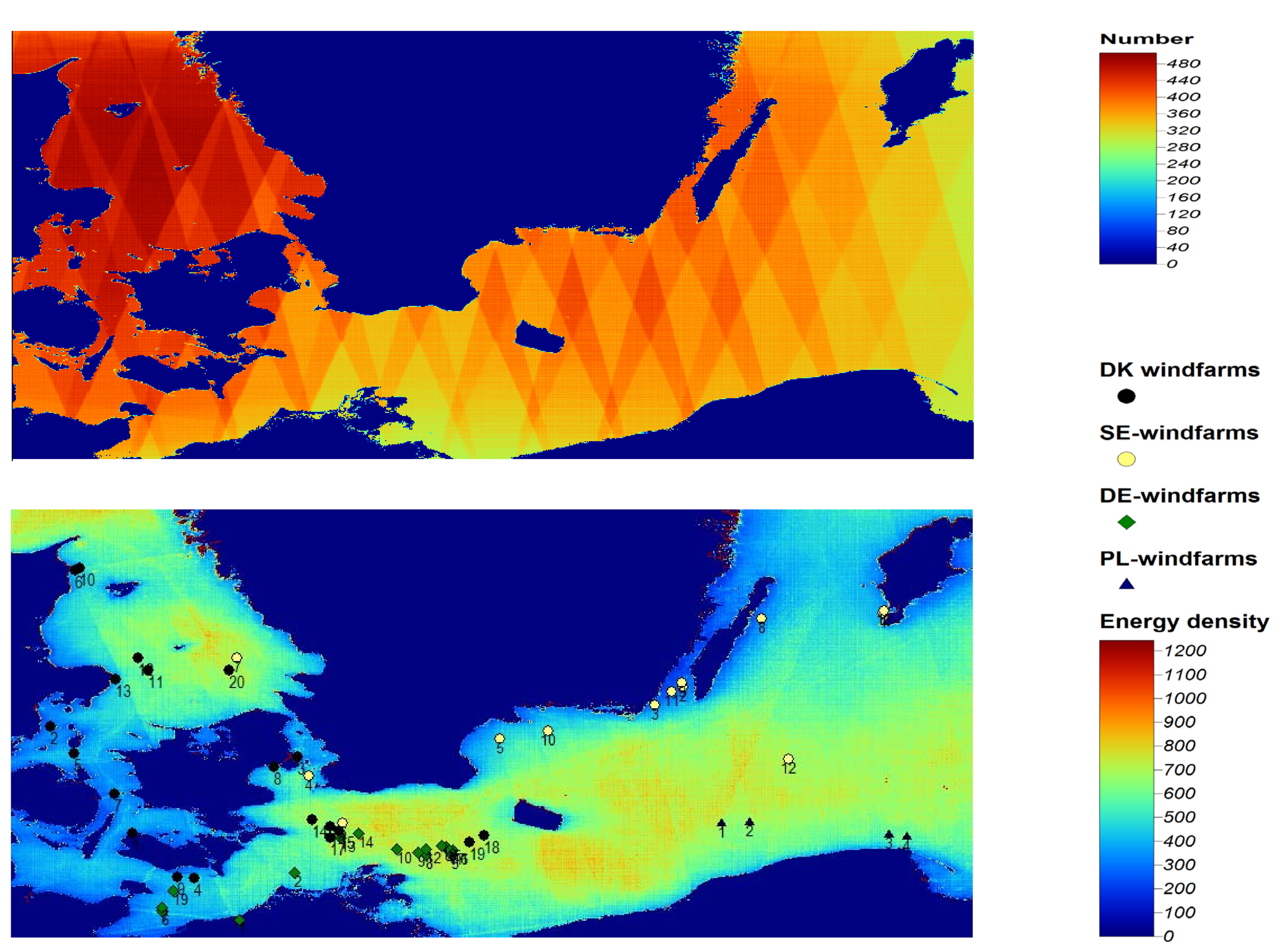
Weibull fitting for scale and shape parameters



Histogram of wind speed observed at FINO-2 extrapolated from 102 m to 10 m from 1 July, 2007 to 19 October, 2010 total of 146910 samples (in grey) with Weibull fit using WAsP, and wind speed observed from Envisat ASAR from 2003 to 2010, total of 409 samples (in black) with Weibull fit using WAsP.

Wind resource statistics are compared only at FINO-2, showing Weibull A to deviate ~2% between *in situ* and SAR-based results, but Weibull k to deviate ~16%. The power density is found to deviate ~29%

Number of SAR wind maps and estimated energy density



Wind resource statistics based on 1009 Envisat ASAR wide swath mode satellite wind maps covering part of the Baltic Sea and interior Danish Seas. Panels top: **(a)** number of samples, below **(b)** wind power density (W m^{-2}) including indication of wind farms.

Lifting of winds from 10 m to hub-height

Recent advances
- which make the lifting of satellite wind fields possible:

- •A validated description of vertical wind profiles at high levels is available
- •Satellite SAR imagery is available in larger quantities (500-1000 overlapping scenes over sites in the European Seas)
- •Wind retrieval algorithms produce Equivalent Neutral Winds (ENW)
- •Mesoscale modeling has been performed for significant areas and time periods
- •Offshore measurements are available for validation (masts and LiDAR)

Conclusion

The study presents SAR-based ocean winds compared to wind observations from 10 meteorological masts erected specifically for wind energy mapping in part of the Baltic Sea. Around 900 collocated pairs of Envisat ASAR wide swath mode images and *in situ* data, show the wind speed to be mapped with root mean square error 1.17 m s^{-1}, bias −0.25 m s^{-1}, standard deviation 1.88 m s^{-1}, and correlation coefficient R^2 of 0.783.

Using more than 1000 Envisat ASAR wind maps, SAR-based wind resource statistics are examined for the 12 existing and 42 planned wind farms in the study area. It is found that the variation in mean wind is highly variable in the near coastal zone from 0 to 20 km.

Wind resource statistics are compared only at one meteorological mast, FINO-2, showing Weibull A to deviate ~2% between *in situ* and SAR-based results, but Weibull k to deviate ~16%. The power density is found to deviate ~29% which is considerably higher than found in a recent study in the North Sea using *in situ* data from three masts. In the North Sea, the deviations between masts data and SAR-based results were within 7% on Weibull k and power density using approximately a similar number of samples and similar wind retrieval.

Work in on-going in the EU-Norsewind project on lifting of winds to hub-height.

References

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[2] Badger et al. 2012 *EWEA conference proceedings, 9 pages.*
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